Dual-Use Hydrostatic Bearing Technology

Christopher J. Bramon/LA40
205–544–2800

A multiagency, multicontractor team is developing a reliable, long-life, cost-effective rotor support system for advanced chillers and liquid rocket-engine turbomachinery. The incorporation of hydrostatic bearings into advanced air-conditioning systems is key to creating a high-efficiency product line that will save $58 million of electricity annually. Long-life turbopumps will significantly reduce military and commercial payload costs and help the United States become cost-competitive and reclaim a majority share of the international launch vehicle market.

Current bearing systems limit the life, reliability, and performance of air-conditioning compressors and rocket engine turbopumps. Hydrostatic bearings replace conventional rolling-element bearings with high-pressure fluid in a noncontacting, low-friction, highly reliable bearing that emphasizes design simplicity, low cost, and long life. Life limitations due to continuous wear of contacting components are eliminated with this system. Critical issues in the design of hydrostatic bearings are the effects of short-duration transient wear during start and stop cycles and the performance of the bearing when using compressible fluids. This program will validate a design system to address these issues and transition the technology to new production programs.

Specific objectives include:

- Validating a hydrostatic bearing design code for compressible fluids
- Conducting transient wear tests of rub-tolerant materials in R134a and liquid hydrogen
- Measuring static and dynamic performance of hydrostatic bearings operating in a compressible liquid (varying supply pressure, pocket-area ratio, pocket depth, orifice geometry, orifice orientation, fluid-bulk compressibility, speed, and operating eccentricity)
- Testing heating, ventilation, and air-conditioning bearings in chiller/compressor components and in new chiller prototype system.

The Dual-Use Hydrostatic Bearing Technology Program started in March 1995 as a 2-year base program with two 1-year options. The base program is dedicated to conducting extensive component performance and wear testing. Options provide for technology transition of an advanced industrial chiller prototype incorporating hydrostatic bearings. This technology could have a pervasive impact on both the space-propulsion and the heating, ventilation, and air-conditioning industries.

A typical industrial chiller unit consists of a centrifugal compressor driven through a set of gears by a hermetically sealed electric motor. The compressor pressurizes the refrigerant, which passes through both an evaporator and a condenser. Oil is used to ensure proper lubrication of the gears and bearings. Although essential for the successful operation of existing systems, oil reduces heat-transfer efficiency in the condenser and evaporator. The elimination of oil requires a new and innovative approach to the entire system. Carrier Corporation has selected an approach that employs a direct-drive (motor-to-compressor), high-speed system incorporating process-lubricated hydrostatic bearings to remove the need for oil-lubricated gears and bearings.

The resulting direct-drive system will be more efficient due to the elimination of gear mechanical losses, improved aerothermomechanical design, and improved heat-transfer performance in the evaporator and condenser. Compared to the current product line, this new family of direct-drive centrifugal equipment incorporating hydrostatic bearings will be 18 percent more efficient. For a typical 400-ton unit user in Atlanta, Georgia, a power savings of $16,000 annually is expected. Based on the increased market projected for 1997, the average annual power savings for the new Carrier units will be $58 million.

Rapid, reliable, and low-cost access to space is absolutely critical for supporting and maintaining the Nation’s space assets with no degradation in mission capability. Current U.S. expendable and reusable space launch vehicles, which typically have launch-preparation times ranging from 85 to 365 calendar days, simply do not meet the launch-on-demand criteria required for responsive and timely replenishment of space assets. Without exception, the propulsion systems of these launch vehicles are characterized by short lifetimes, high maintenance, and extensive ground support. As a result, launches are infrequent, costly, and militarily unresponsive.

To achieve the goals of military responsiveness and affordable commercial launch services, advanced propulsion systems must combine low operational and maintenance costs with increased safety and reliability. A cost analysis of a long-life reusable turbopump, comparing rolling-element bearings versus hydrostatic bearings, indicated a savings of $1.8 million per hour of turbopump operation over hydrostatic bearings. The U.S. commercial launch industry is competing in the work market with private launch vehicles derived from ballistic missiles developed in the 1950's and 1960's. Although the U.S. once dominated the market for commercial launch services (fig. 114), continued reliance on these aging expendable launch vehicles and propulsion systems has significantly reduced cost competitiveness. The U.S. has lost the leadership in commercial launch services to France and is facing further challenges by highly subsidized Japanese, Chinese, and Russian aerospace companies. Launch costs reductions in excess of 50 percent may be required. The National Space Council's 10-Year Space-Launch Technology Plan sets forth a cost goal of $1,000 per pound, which is 22 percent of the current U.S. cost.

Hydrostatic bearings used as the primary rotor support system for cryogenic turbomachinery offer significant design, performance, and durability improvements compared to conventional rolling-element bearing systems. Unlike rolling-element bearings, hydrostatic bearings have no DN (bore diameter × rotor speed) limitations and are not prone to stress-corrosion cracking, rolling-contactfatigue, or bulk-ring fractures due to material or manufacturing defects. Free of these constraints, the shaft speed can be increased for higher operating efficiency. Increased operating speed also helps to reduce the size and weight of the turbomachinery. Additional desirable characteristics include mechanical simplicity, accuracy of rotor position, high or low stiffness, lack of rotating-to-static part contact during steady-state operation, and excellent damping characteristics for improved rotordynamic performance. These key features enable significant reductions in part count and complexity, the use of high-performance unshrouded impellers, and smaller operating clearances that result in increased performance and longer life at a lower cost.

Two major factors that determine the successful operation of a hydrostatic bearing are performance and durability. Performance includes such factors as flow rate, load capacity, drag torque, stability, and the dynamic coefficients—stiffness, damping, and inertia. Pratt & Whitney's test program will evaluate bearing performance, while the Phillips Laboratory will address rub tolerance of various shaft/stator material combinations. The hydrostatic bearing test rig being used in this program is shown in figure 115. In addition to developing the advanced chiller system, Carrier has fabricated and delivered a high-pressure, self-contained, closed-loop R134a system to support the extensive test program. This system allows testing with an ambient-temperature fluid that approaches the compressibility of cryogenic liquid hydrogen at a significantly lower cost. By the end of

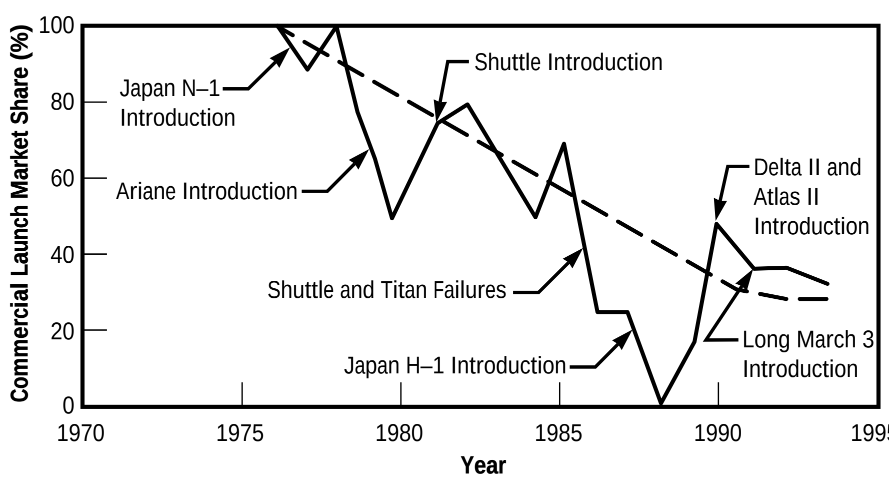

FIGURE 114.—U.S. share of commercial launch market (from National Space Council's 10-Year Space-Launch Technology Plan).

1995, the Phillips Laboratory will have concluded the liquid-hydrogen material test program and Pratt & Whitney will have started the R134a performance testing.

Both the aerospace and the heating, ventilation, and air-conditioning industries require advanced rotor-support systems to improve reliability, efficiency, and life, while lowering procurement and operating costs. These advanced rotating machinery systems are necessary to position the United States to compete successfully in the growing international marketplace. Joint technology investment programs, using the expertise and resources of both government and private industry, are a cost-effective means to meet military and economic security goals.

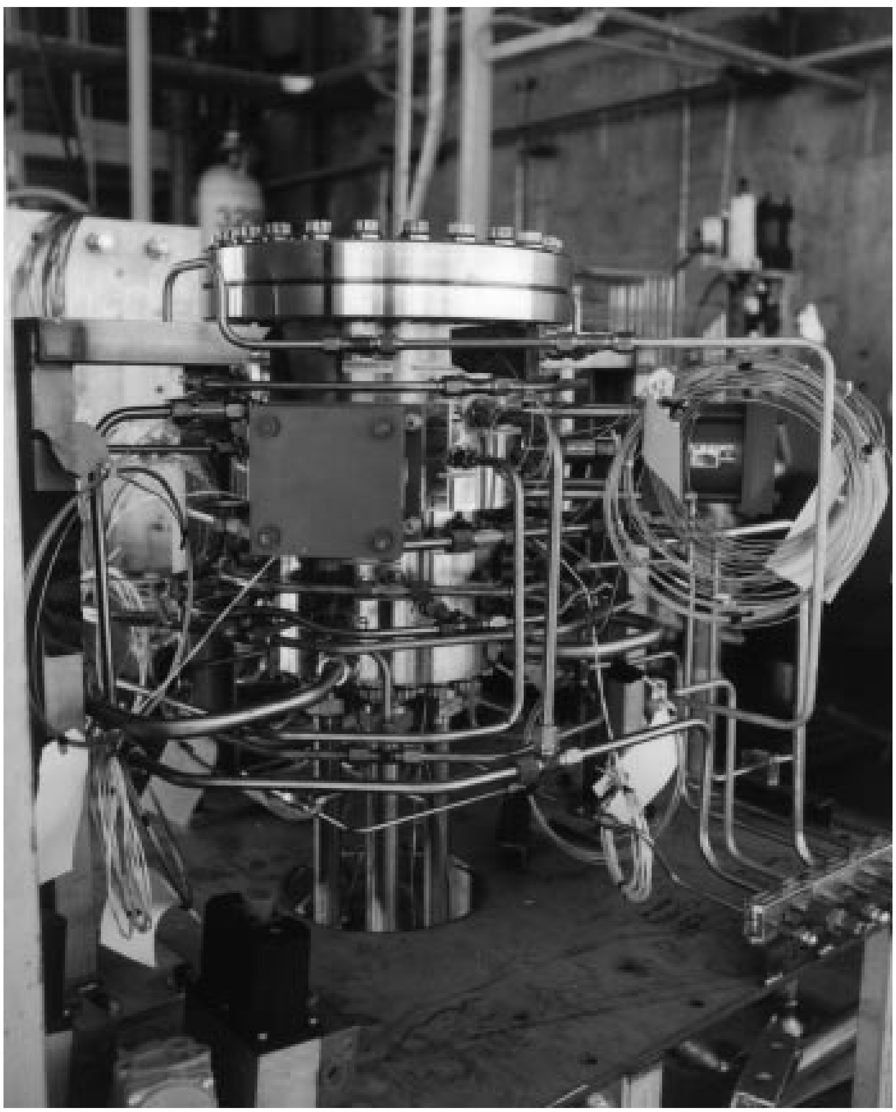

FIGURE 115.—Hydrostatic bearing test rig.

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